Andrew Yip
Pacific Gas and Electric Company (PG&E)

PG&E HIGH PENETRATION SOLAR PV
CURRENT STATUS AND RESEARCH
PG&E Overview

Company Facts
- Fortune 200 company located in San Francisco, CA
- $14B in operating revenues in 2010
- 20,000 employees

Energy Supply
- Services to 15M people:
  - 5.2M Electric accounts
  - 4.3M Natural Gas accounts
- Peak electricity demand: 20,000 MW
- Over 50% of PG&E’s electric supply comes from non-greenhouse gas emitting facilities

Service Territory
- 70,000 sq. miles with diverse topography
- 160,000 circuit miles of electric transmission and distribution lines
- 49,000 miles of natural gas transmission and distribution pipelines
**PG&E Renewable Energy Programs**

### Available PG&E Programs
- California Solar Initiative
- Solar Water Heating (CSI Thermal)
- Self Generation Incentive Program
- Net Energy Metering
- Feed-in Tariff Programs

### System Size
- 1 kW
- 100 kW
- 1 MW
- 3 MW
- 20 MW
- 100 MW ++

#### Customer-scale
- Renewable Auction Mech.
- PV RFO
- Renewables RFO
- Utility Owned

#### Utility-scale
- in regulatory proceeding

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**2013 Solar Forum 2013**

**Feb 13-14, San Diego, CA**
Note: Customer-Side Solar PV Online value includes projects associated with various customer-side incentive programs. In-development and PG&E Program Cap value only includes projects in the California Solar Initiative mass market program.
PG&E and Distributed PV

- PG&E is a leader in distributed PV
  - > 79,000 installations
  - > 802 MW (CEC AC)
  - ~30% of US total
  - PG&E serves ~5% of US population
  - Over 17,000 interconnections in 2012

![Graph showing the number of interconnections from 2000 to 2013]

- PG&E serves ~5% of US population
- Over 17,000 interconnections in 2012
PV Penetration Status

- Overall high penetration of PV in PG&E territory (relative to other utilities)

- However, feeder-level penetration is generally low (relative to feeder max demand)

- On the other hand, high concentrations of PV exist in some localized areas (i.e., on individual transformers)
PV Penetration by Circuit

PV Penetration* on PG&E Feeders

% Penetration*

0% 10% 20% 30% 40% 50% 60% 70% 80%

0 - 2% 2 - 4% 4 - 6% 6 - 8% 8 - 10% 10 - 12% 12 - 14% 14 - 16% 16 - 18% 18 - 20% >20%

* % PV Penetration = PV MW (CEC AC) / 2009 Feeder Max Demand
Currently, DG penetration is low at about 5% of System Peak

Penetration = installed DG as a % of total system peak (22,000MW)
At Low Penetration, DG System Impacts are Manageable

- All DG’s are studied individually for potential impact and mitigated prior to physical interconnection
  - Studies focus on Safety, Equipment Loading, Voltage Fluctuation and Islanding
- For most feeders, aggregate DG is less than local load, and power flows on the feeders are still from the substation out in a radial mode
- All identified issues are mitigated to have less than significant system impacts
## Voltage Concerns

<table>
<thead>
<tr>
<th>Nominal Two-Wire And Multi-Wire Service Voltage</th>
<th>Minimum Voltage To All Services</th>
<th>Maximum Service Voltage On Residential And Commercial Distribution Circuits Class A</th>
<th>Maximum Service Voltage On Agricultural And Industrial Distribution Circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>114</td>
<td>120</td>
<td>126</td>
</tr>
<tr>
<td>208</td>
<td>197</td>
<td>208</td>
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</tr>
<tr>
<td>480</td>
<td>456</td>
<td>480</td>
<td>504</td>
</tr>
</tbody>
</table>

- DG (PV) can impact the voltage profile along a given feeder, driving the service voltage outside of acceptable ranges at points – particularly in low-load conditions.
PV and the Distribution Grid: Challenges

PV can cause...

- **Service voltage** to exceed the acceptable range
  - Can lead to inverter trip-offs (potential domino effect)
- **Flicker**
  - Due to inverter trip-offs or rapid cloud cover

In what cases?

- **High concentrations** of PV beyond a single transformer
- **Large PV** on feeders
- PV at points on feeder **already close to voltage limits**
Voltage Mitigations

Today, voltage impacts of PV on the grid are generally addressed by **adjusting settings** or **relocating** distribution system equipment, including:

- Capacitor banks
- Load tap changers
- Voltage regulators
- Bucking transformers

In certain situations with fast voltage fluctuations due to intermittency, **reconductoring** may be the only effective mitigation measure. **Energy storage** is an alternative but has higher capital cost and market operational uncertainties.
PV and the Distribution Grid: Today

• Examples of grid problems caused by PV and mitigation strategies employed

<table>
<thead>
<tr>
<th>Concern</th>
<th>Mitigation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A facility’s 10-kW PV system (inverter) trips off-line when customer load is light due to high service voltage</td>
<td>Adjust voltage regulator settings</td>
</tr>
<tr>
<td>Generators at a facility downstream of a 1-MW PV system trip off-line due to high service voltage</td>
<td>Adjust capacitor bank settings</td>
</tr>
</tbody>
</table>

• Generally, few impacts today despite the relatively high number of PV systems

• However, requirements for mitigation may increase in future with increased penetration of PV in localized areas
PV and the Distribution Grid: Potential Future Strategies

• In the future, the negative impacts of PV on the grid may be mitigated in a variety of ways

- Install new equipment (e.g., voltage regulators)
- Reconductor lines
- Require curtailment of PV generation
- “Smart” inverters
- Distribution Management Systems (DMS) (e.g., Volt/Var Optimization (VVO))
Current Research for Distributed Solar PV

• Collaborative efforts
  • Development and Analysis of a Progressively Smarter Distribution System (UC Irvine)
  • Advanced Grid-Interactive Distributed PV and Storage (Solar City/Tesla Motors/ UC Berkeley)
  • PV and Advanced Energy Storage for Demand Reduction (SunPower/KEMA)
  • Quantification of Risk of Unintended Islanding and Re-Assessment of Interconnection Requirements in High-Penetration of Customer-Sited Distributed PV (GE)
  • Screening Distribution Feeders: Alternatives to the 15% Rule (NREL/Sandia/CPR)
  • Tools Development for Grid Integration of High PV Penetration (BEW)

• Other research areas
  • Two internal studies to assess the impacts of PV on the PG&E distribution system with separate focus on (a) 1-20 MW systems and (b) smaller (e.g., residential) systems.
  • A DOE SEGIS-funded, EPRI-led project involving National Grid, Excel Energy, and Detroit Edison that will explore how utility-inverter communication can enable “smart” inverters to optimally provide grid support. PG&E is supporting this project in an advisory role.
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Q &A AND DISCUSSION